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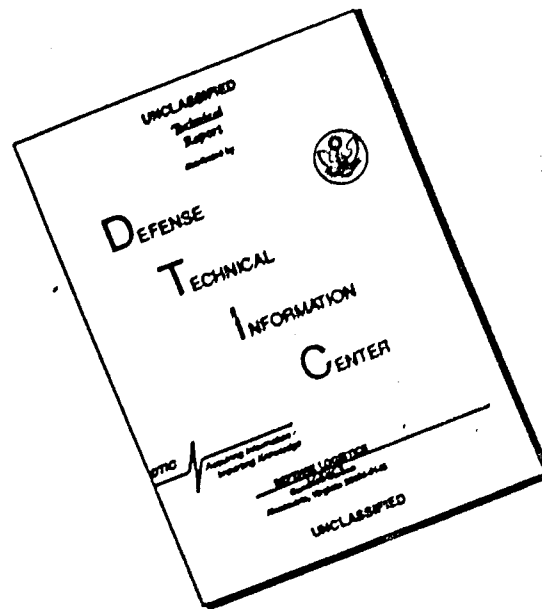
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DETAILED FINAL REPORT OF RESEARCH ON
HIGH-SPEED ROTARY-FIXED WING AIRCRAFT

VOLUME VI

PERFORMANCE CURVES FOR PRESSURE JET
ROTOR DRIVE WITH TIP BURNING

OFFICE OF NAVAL RESEARCH, WASHINGTON BRANCH
PROJECT NR 250-001 CONTRACT N6-001-001

Report 1587

15 February 1950

Serial 14

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DETAILED FINAL REPORT OF RESEARCH ON
HIGH SPEED ROTARY-POWERED WING AIRCRAFT

VOLUME VI

PERFORMANCE CURVES FOR PRESSURE JET ROTOR DRIVE WITH TIP BURNING

SUBMITTED UNDER Contract N6onr-34901 to the Office of Naval Research,
Aeronautical Branch, Project NR 250-001

PREPARED BY

F. L. De Hoff
F. L. De Hoff

APPROVED BY

C. H. Harkins
C. H. Harkins

APPROVED BY

APPROVED BY

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PERFORMANCE CURVES FOR PRESSURE JET ROTOR DRIVE WITH TIP BURNING

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1. INTRODUCTION

For the pressure-jet rotor drive system with tip burning, the following values are calculated for four tip burner combustion temperatures, four tip speeds and seven pressure ratios:

- A. Weight flow per compressor horsepower
- B. Duct area required for an internal duct velocity of 200 fps per compressor horsepower
- C. Compressor outlet temperature
- D. Tip jet thrust per compressor shaft horsepower
- E. Specific fuel consumption of compressor and burner per pound of tip jet thrust
- F. Duct area required for an internal duct velocity of 200 fps per pound of tip jet thrust
- G. Exhaust velocity

The results are plotted in Charts 1 through 71.

2. ASSUMPTIONS

The following assumptions have been made:

- A. Inlet air is NACA standard sea level

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- ORIGINAL
- B. Adiabatic compressor efficiency is 80 percent
 - C. Compressor engine specific fuel consumption = .65 lbs./HP hour
 - D. Tip fuel heat content = 18,000 BTU/lb.
 - E. Combustion efficiency = 90 percent
 - F. Nozzle efficiency = 95 percent
 - G. Adiabatic head of all losses equals head of pressure gain (for corrections for deviation from this value, see paragraph 6)
 - H. Internal duct velocity = 200 fps (for explanation, see paragraph 4)

3. NEGLECTED ITEMS

The following items have been neglected:

- A. Leakage losses (should be well below 1 percent of total flow)
- B. Losses or ram gains in front of compressor inlet
- C. Deviations of blade internal pressure from compressor outlet pressure (has a small influence upon density and consequently duct area requirement)
- D. Variations of combustion efficiency with temperature rise (such as caused by dissociation). Cannot be included without complete burner test data.

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E. Heat losses through blade (10 percent loss results in about 1 percent error in burner specific fuel consumption)

4. INTERNAL DUCT VELOCITY

An arbitrary value of 200 fps has been chosen. The compromise between aerodynamic and thermodynamic considerations will prescribe the actual velocity to be selected. This optimum compromise cannot be generally determined because it depends upon too many variables, such as:

- A. Percentage blade cross section available for duct. This depends on design effort, blade balance requirements, structural requirements, and blade weight considerations.
- B. Percentage hovering time in total flight time. On a VTO aircraft, the best compromise for hovering is not correct for the average operation.
- C. The mission. To find an optimum compromise, it must be known whether an optimum of range, of cost or of any other desirable characteristic is sought.

Once the optimum velocity is determined, the duct areas can be found by using the areas for 200 fps and correcting them for the new velocity.

5. EQUALITY OF LOSSES AND GAINS

In paragraph 2G it was assumed that the loss in adiabatic head resulting

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from the sum of all pressure losses was equal to the gain in head resulting from air compression inside the rotating blade. When K denotes the ratio of loss to gain:

$$K = \frac{\lambda \frac{PP}{4A} \frac{V^2}{2g}}{\frac{(P\Omega)^2}{2g}}$$

Wherein: λ = friction coefficient
 R = rotor radius = duct length
 P = perimeter of internal duct
 A = duct cross-sectional area
 V = velocity in blade
 Ω = rotor angular velocity

$$\frac{RP}{4A} = R \text{ constant } \frac{C}{C^2} = \text{constant } \frac{R}{C} = \frac{\text{constant}}{\sigma}$$

where σ denotes the rotor solidity.

Therefore,

$$K = \frac{\lambda}{\sigma} \text{ constant } \left(\frac{V}{R\Omega} \right)^2$$

It can be seen that K remains unaffected by pressure ratio and temperature rise in the burner. $\frac{V}{R\Omega}$ is a measure of the relative importance attached to external and internal losses and for families of rotors of constant $\frac{V}{R\Omega}$ solidity becomes the main variable that affects K. If, for

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VTO rotors of high disc load, $R\Omega$ is chosen as high as possible, optimum solidity will increase with disc load in order to keep the specific blade loading an optimum. This shows that low K values (low losses) can be achieved by high disc loads.

Also for constant disc load and constant $\frac{V}{R\Omega}$, K will remain constant and the trends shown by the subject calculations will be correct.

6. CORRECTIONS FOR DEVIATIONS FROM K = 1

In most cases, of course, general considerations will result in a choice of $\frac{V}{R\Omega}$ and σ that result in K unequal unity.

The physical effect of a change of K is an increase or decrease of burner pressure and, consequently, exhaust velocity. All results plotted in charts 2 through 20 are based on thrust and therefore on the difference between exhaust velocity and tip speed. A change in exhaust velocity under equal compressor and burner temperature conditions can therefore be accounted for by reading the desired data at a tip speed that differs from the actual tip speed by the amount $\Delta\omega R$ that equals the change in exhaust velocity resulting from deviation of K from unity.

A simple way to find $\Delta\omega R$ is shown in the following. It should only be used when the total gain or loss in head does not exceed ± 15 percent of the total head, an assumption that covers all practical cases.

$$K = \frac{h_{\text{loss}}}{h_{\text{gain}}}, \Delta h = h_{\text{gain}}(1 - K) = \frac{(\Omega R)^2}{2gJ} (1 - K)$$

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$$V_j = \eta_n \sqrt{2gJh_{ad}}$$

$$V_{j \text{ actual}} = \eta_n \sqrt{2gJ(h_{ad} + \Delta h)} \approx \eta_n \sqrt{2gJ h_{ad} \left(1 + \frac{\Delta h}{h_{ad}}\right)}$$

Wherein: J = heat equivalent

 η_n = nozzle efficiency (95 percent) h_{ad} = adiabatic head at nozzle V_j = exhaust velocity

Therefore:

$$\Delta V_j = \Delta \Omega_R = V_j \frac{\Delta h}{2h_{ad}}, \quad h_{ad} = \frac{\left(\frac{V_j}{\eta_n}\right)^2}{2gJ}$$

$$\Delta \Omega_R = V_j \frac{\frac{(QR)^2(1-K)}{2gJ}}{\frac{V_j^2}{\eta_n^2 2gJ}} = \frac{(QR)^2(1-K)}{V_j} \frac{\eta_n^2}{2}$$

Figure 21 allows to determine V_j for various temperature and pressure ratio conditions.

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COMPRESSOR WEIGHTFLOW, OUTLET TEMPERATURE,
AND PRESSURE DUCT AREA REQD FOR 200 FPS
IN DUCT) VS. PRESSURE RATIO.

$M_c = .80$

STANDARD SEA LEVEL TEMPERATURE

WEIGHTFLOW PER H_2 , LBS/SEC. P
OUTLET TEMPERATURE, °F
DUCT AREA PER H_2 FOR 200 FPS, IN²/P

WEIGHTFLOW
DUCT AREA PER P
COMPRESSOR PRESSURE RATIO

6/1

5/1

4/1

3/1

2 1/2

2/1

1 1/2

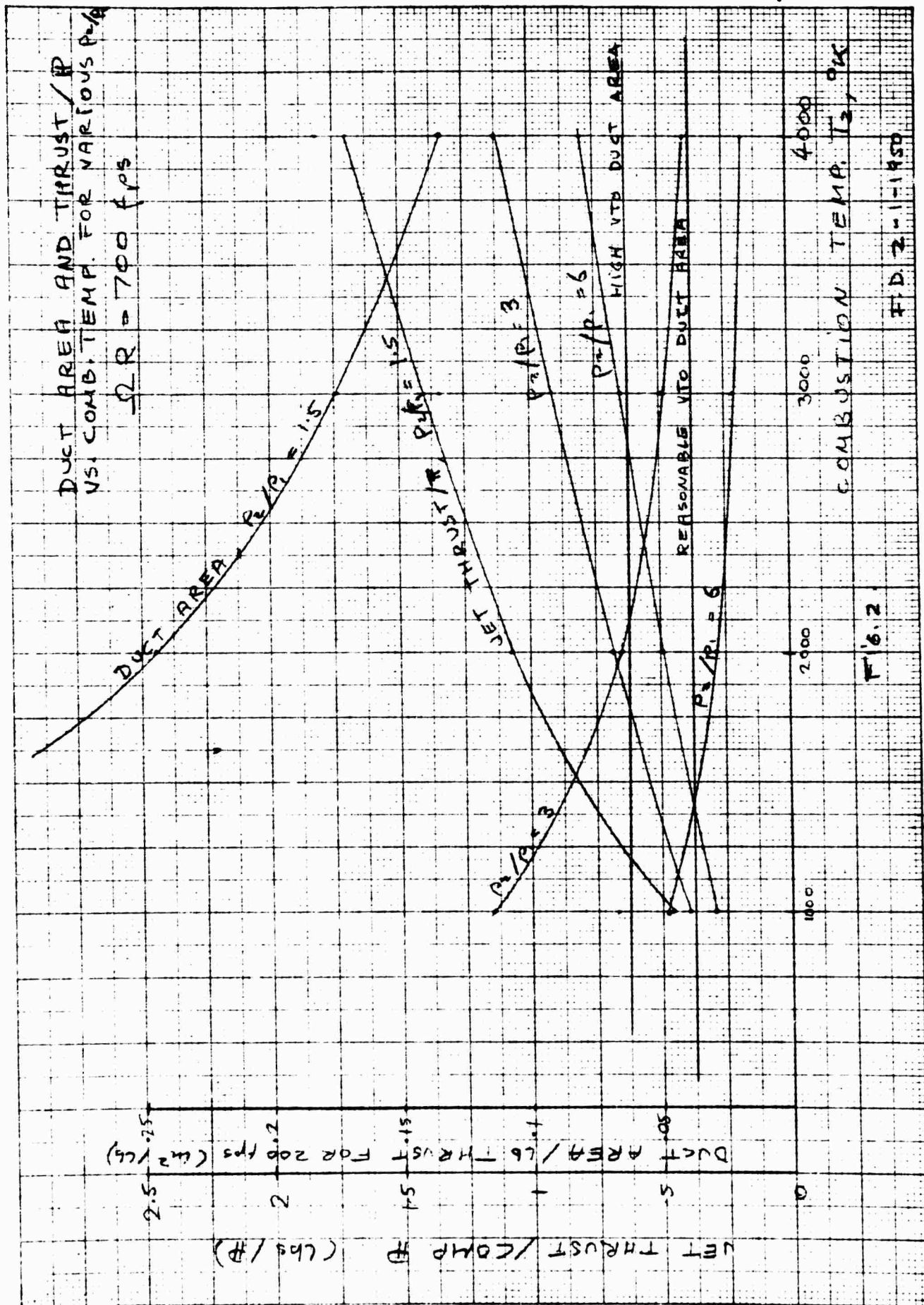
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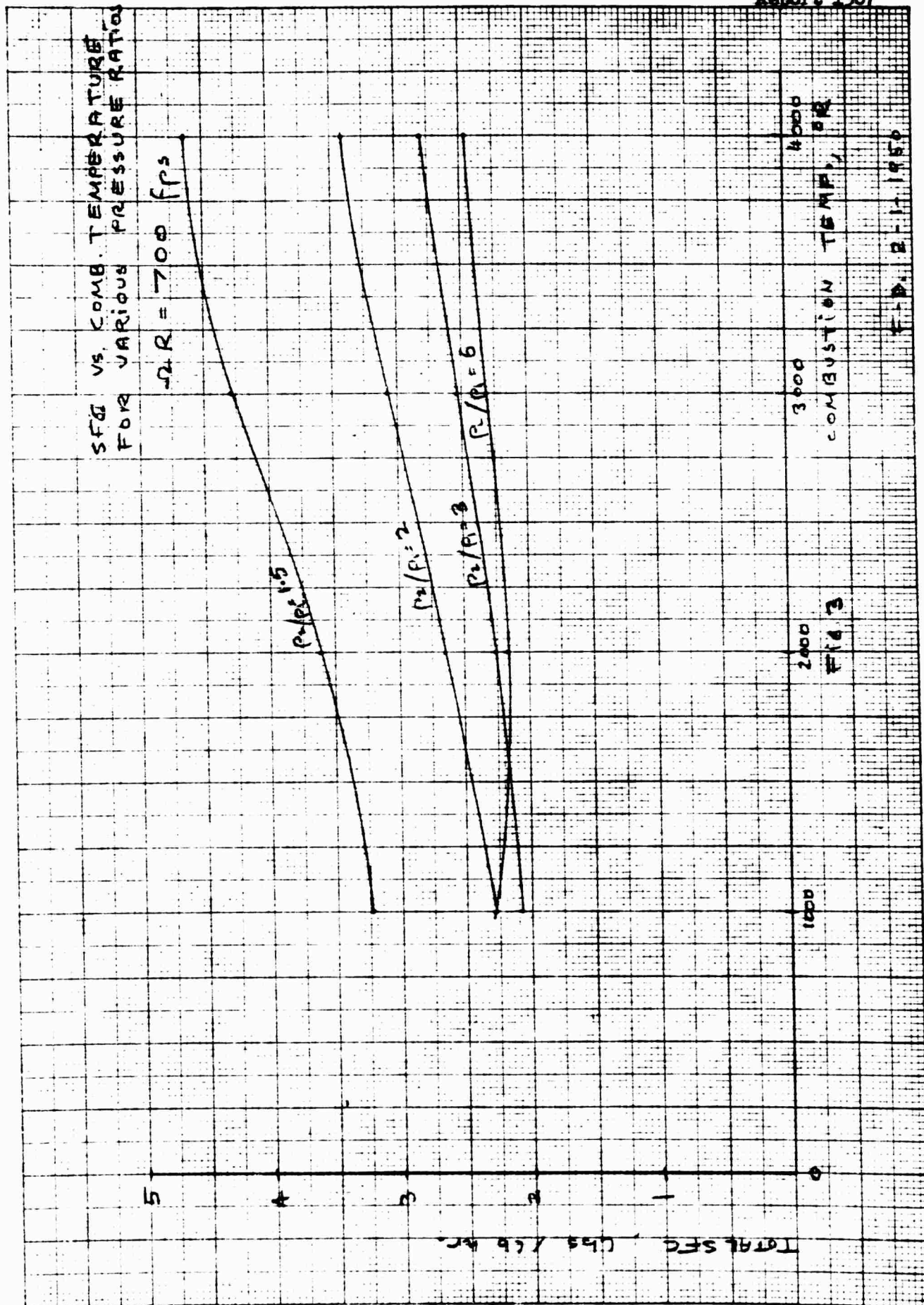
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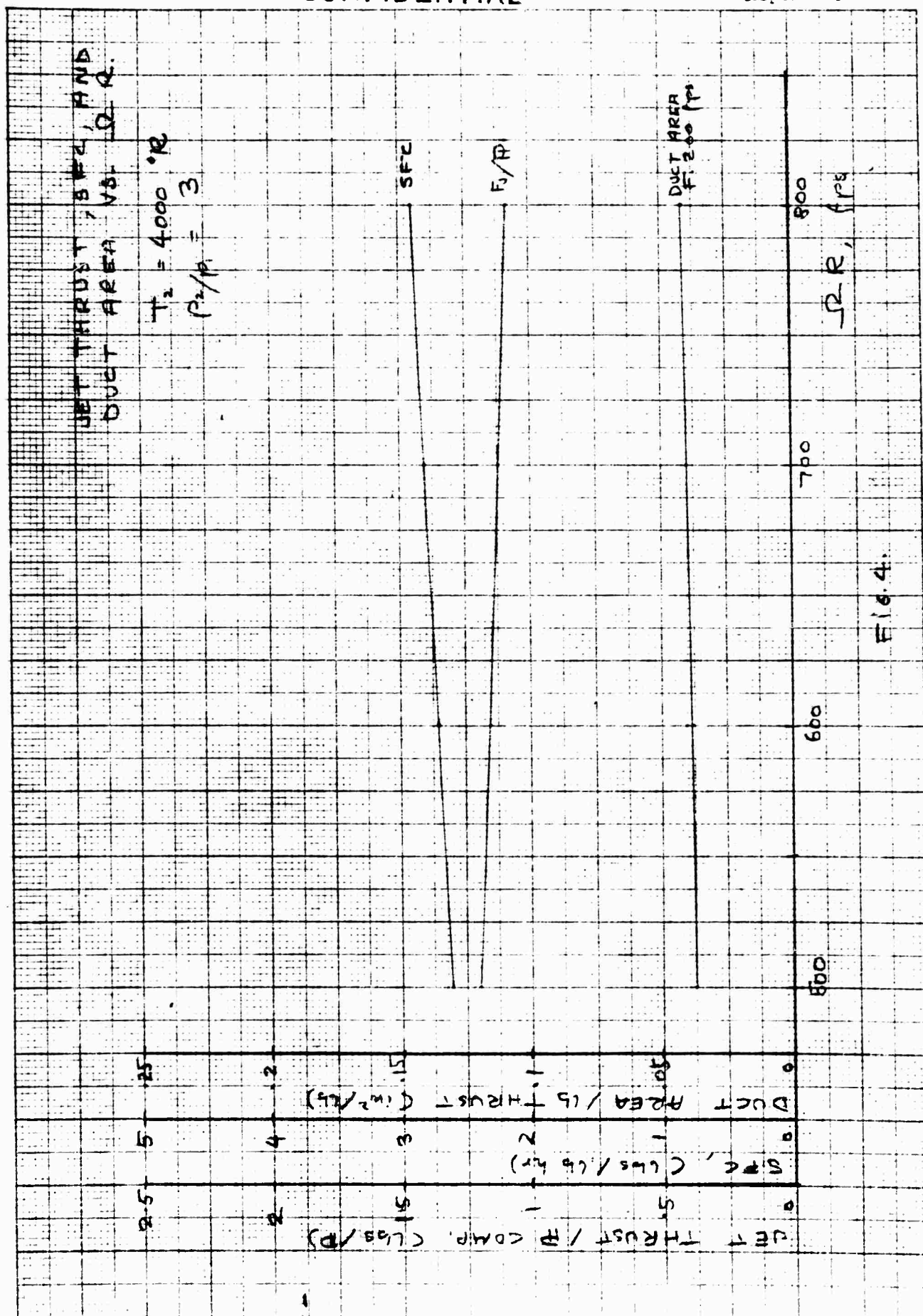


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JET THRUST, SFC AND
DUCT AREA VS. P_2/P_1

$T_2 = 1000^\circ R$

$\Omega R = 500 \text{ FPS}$

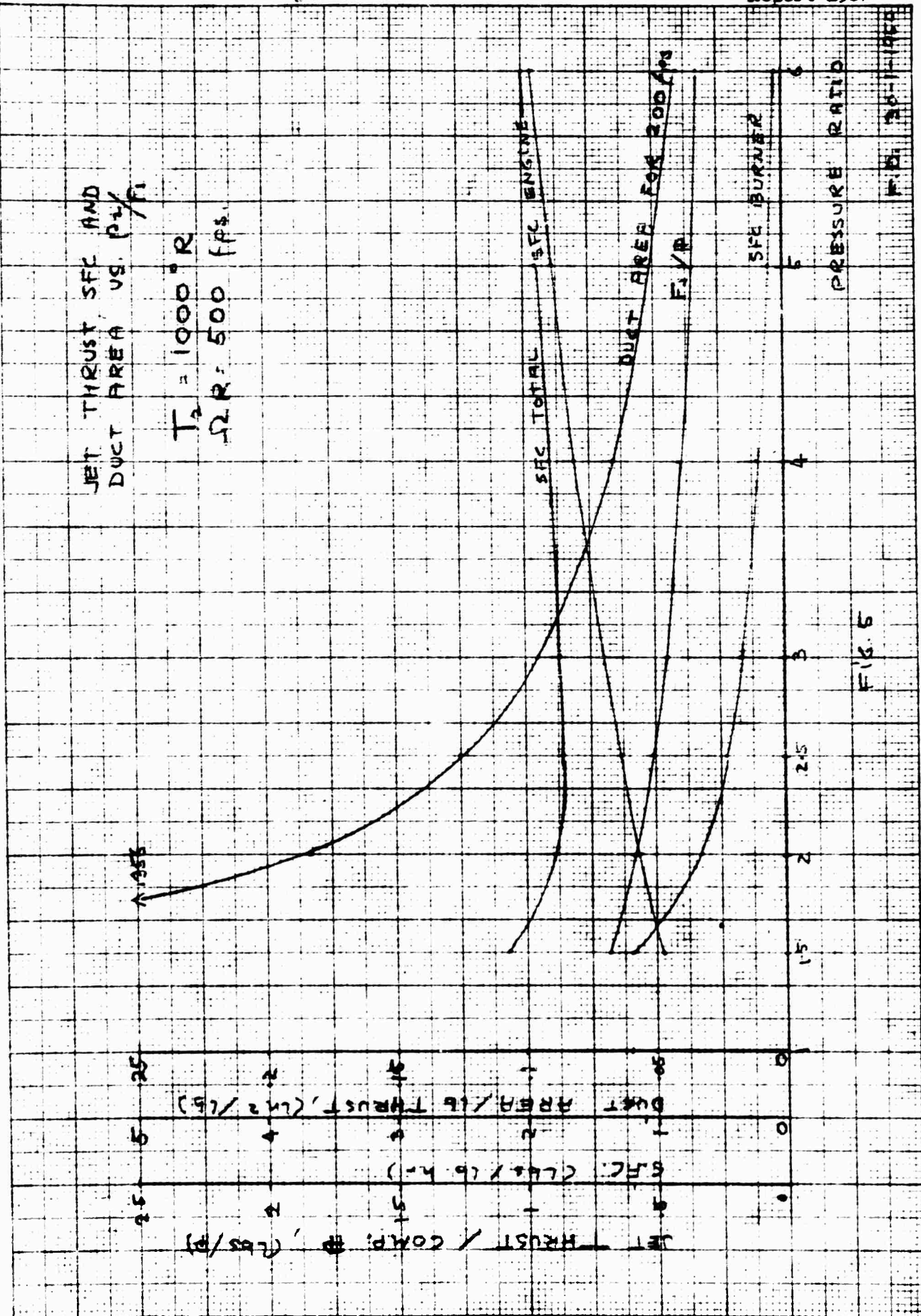
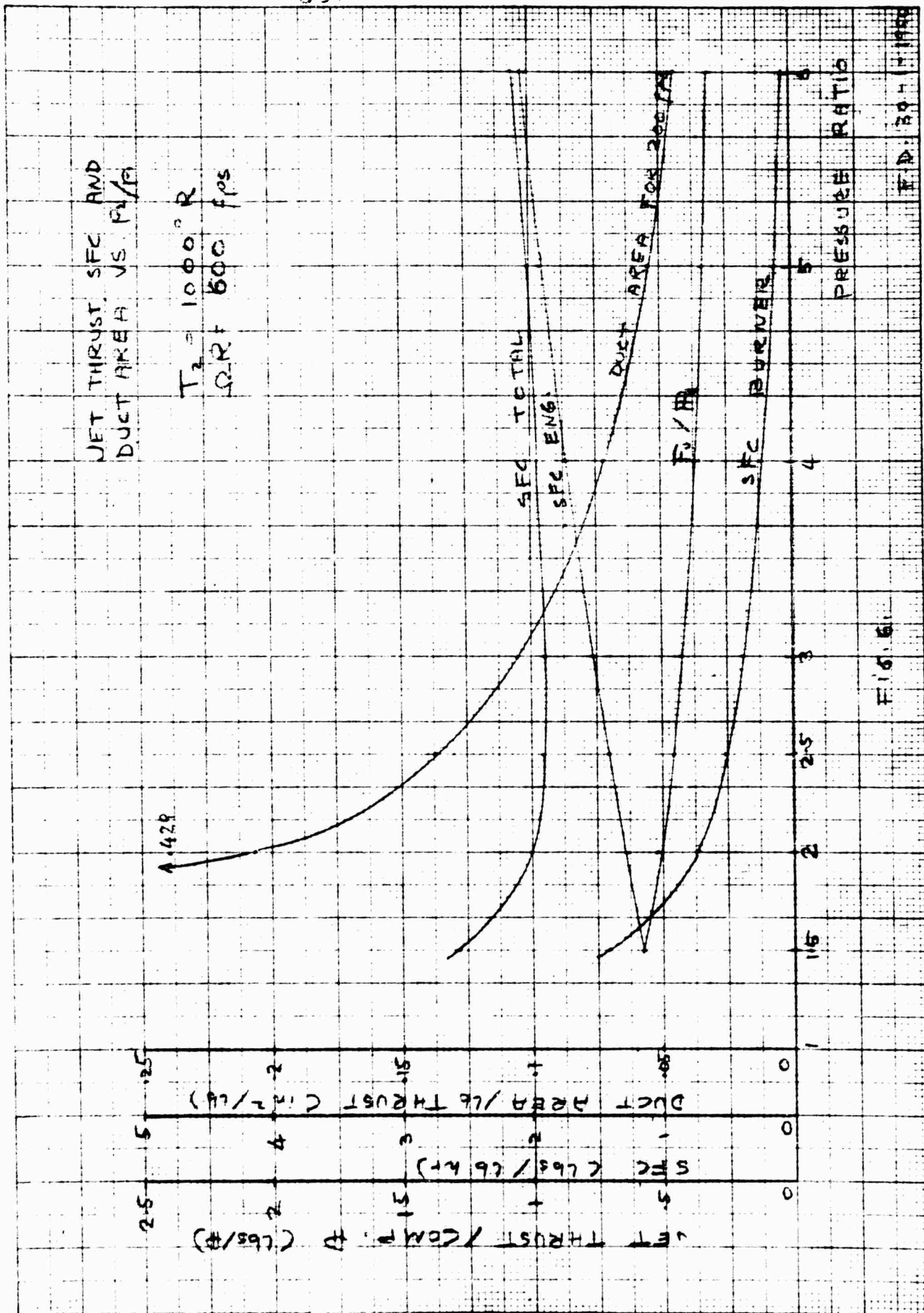


FIG. 5

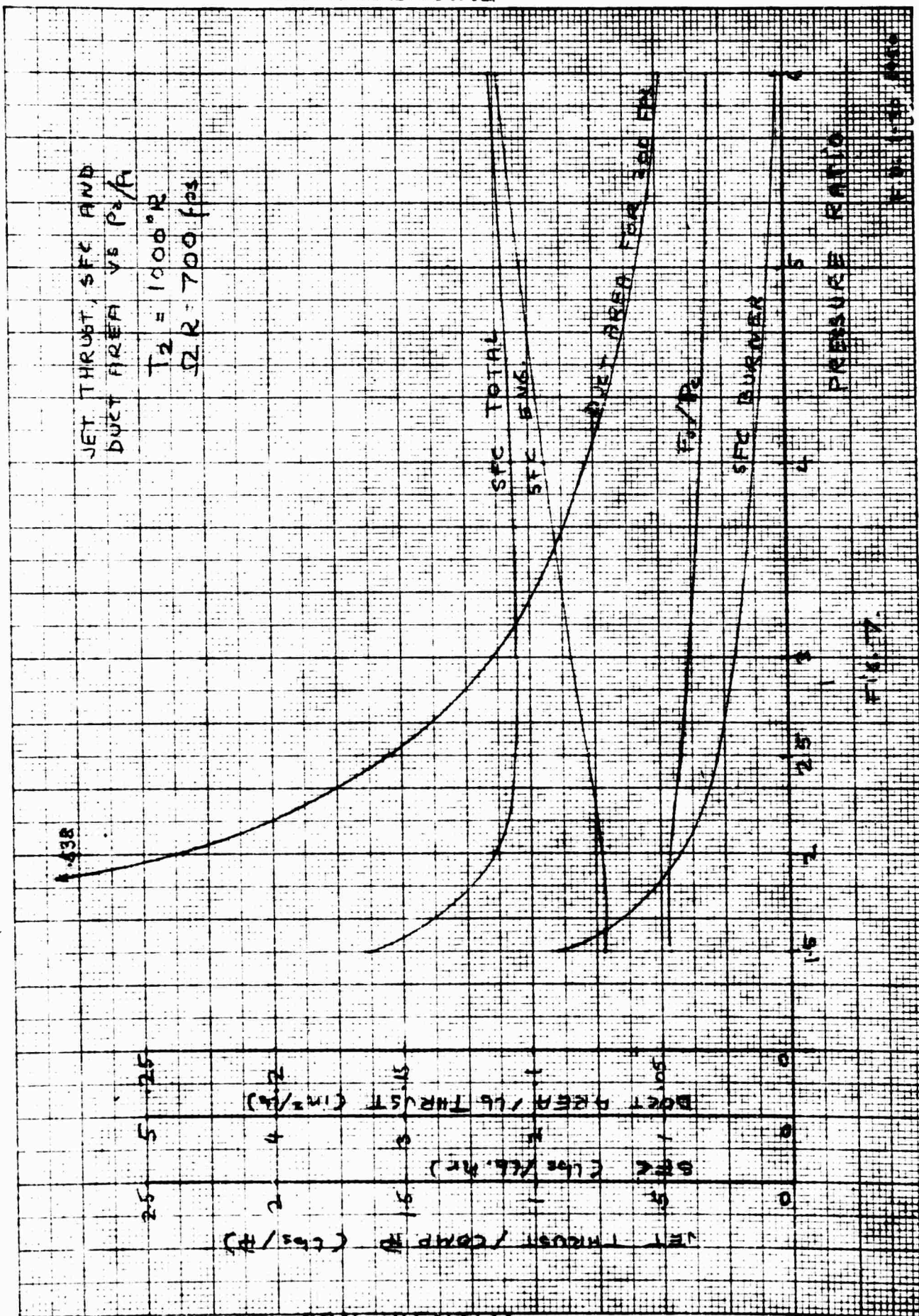
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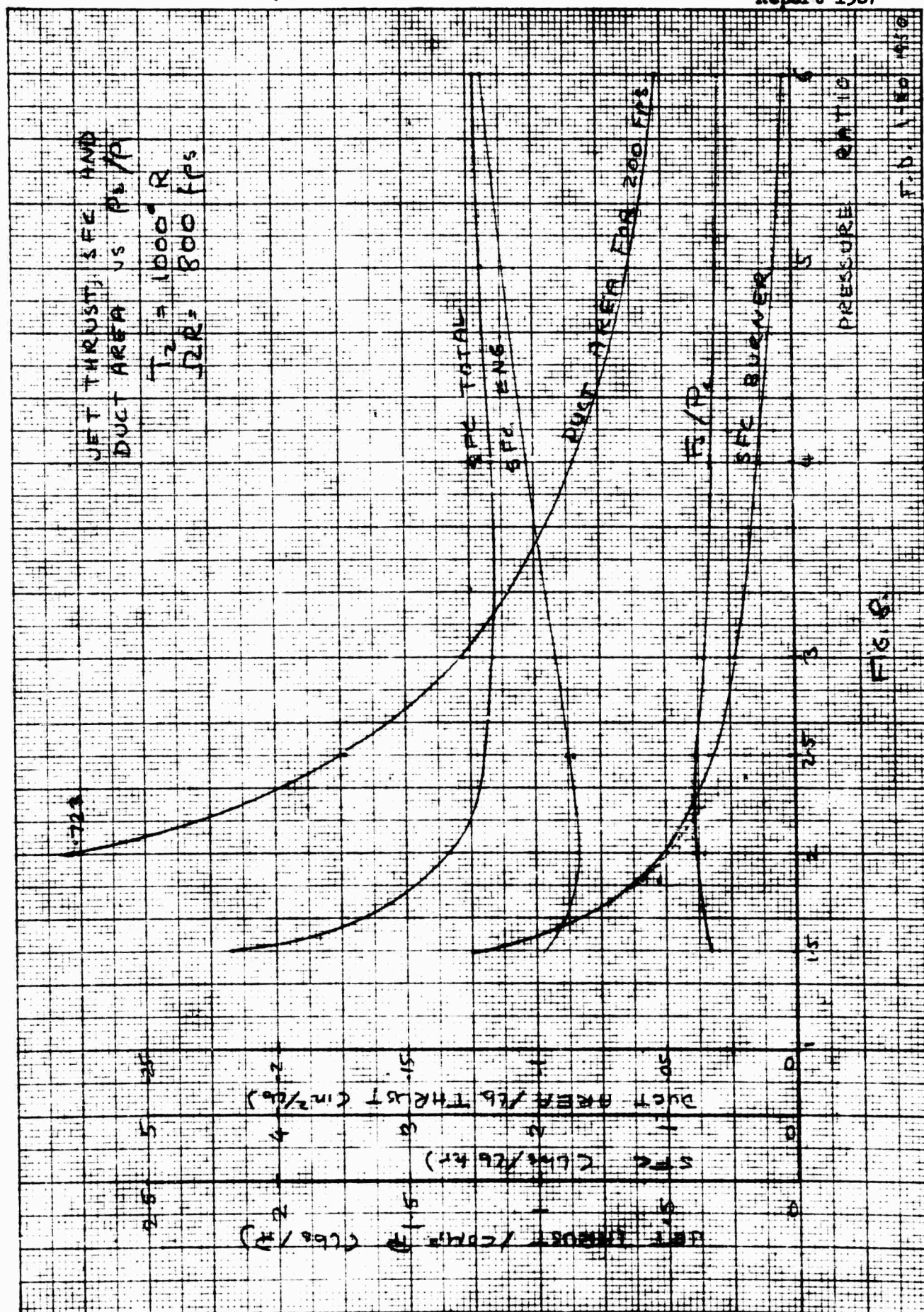
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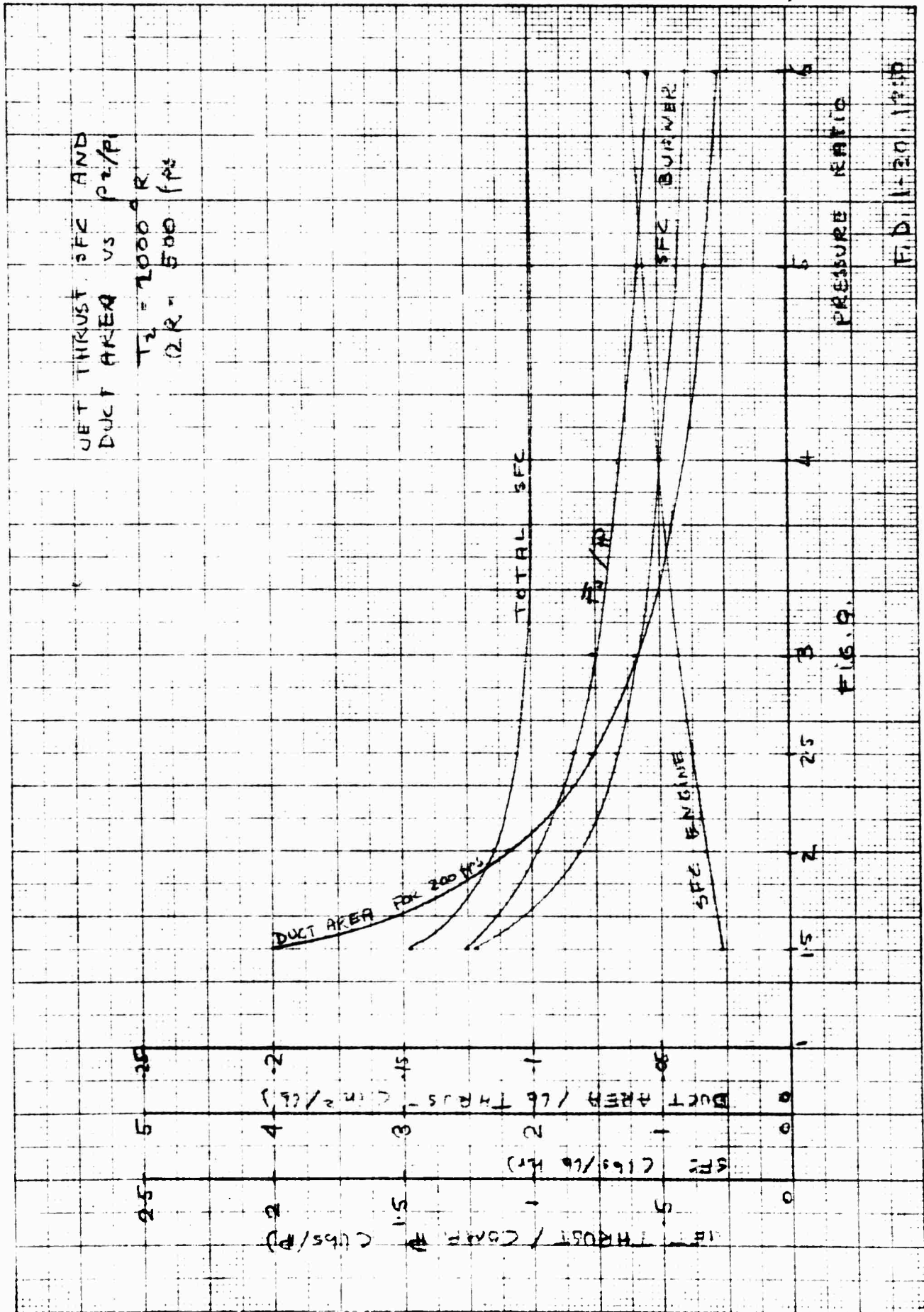


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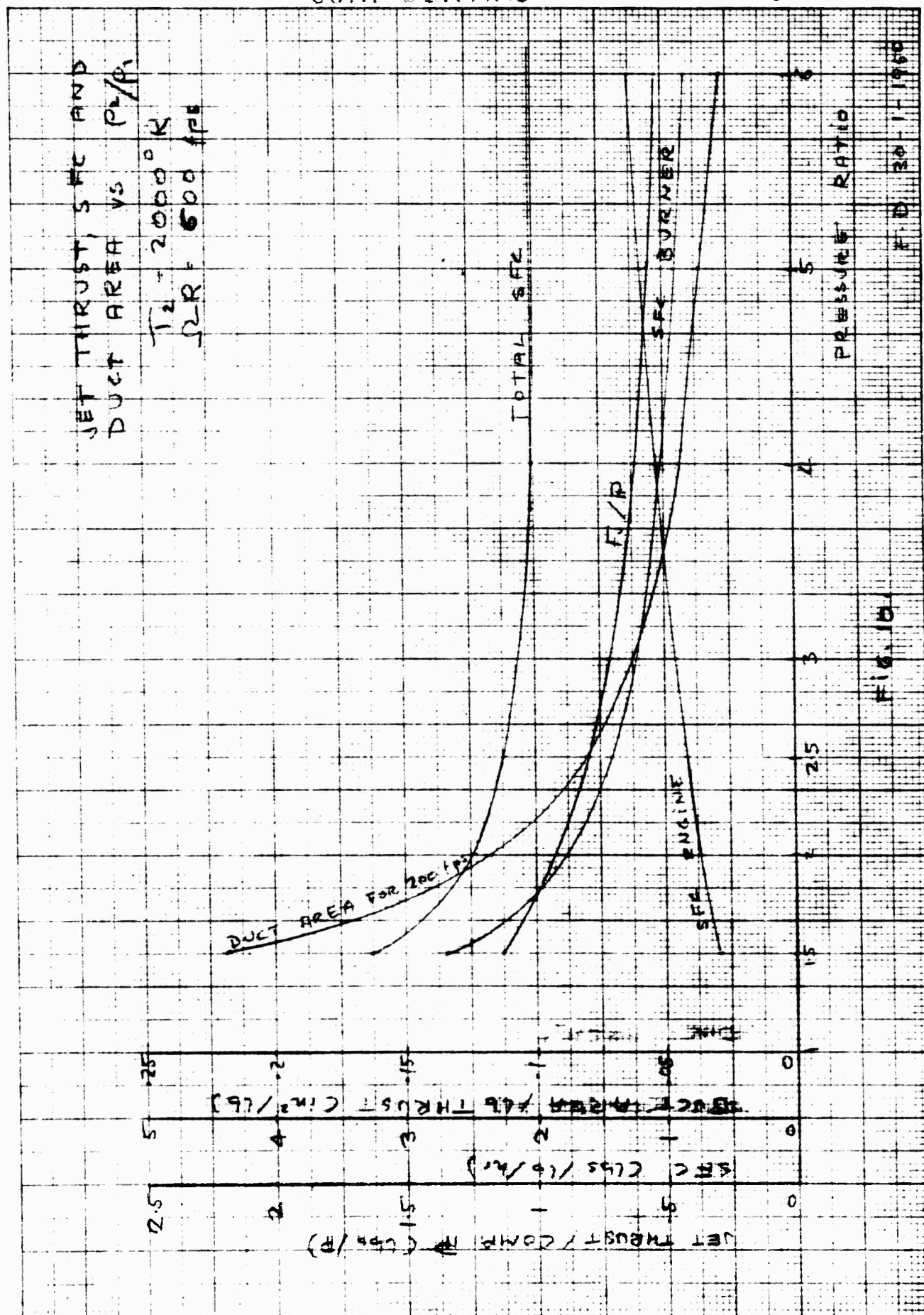
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JET THRUST, SFC, AND
DUCT AREA VS P_2/P_1

$T_2 = 2000^\circ R$
 $SR = 700 \text{ fps}$

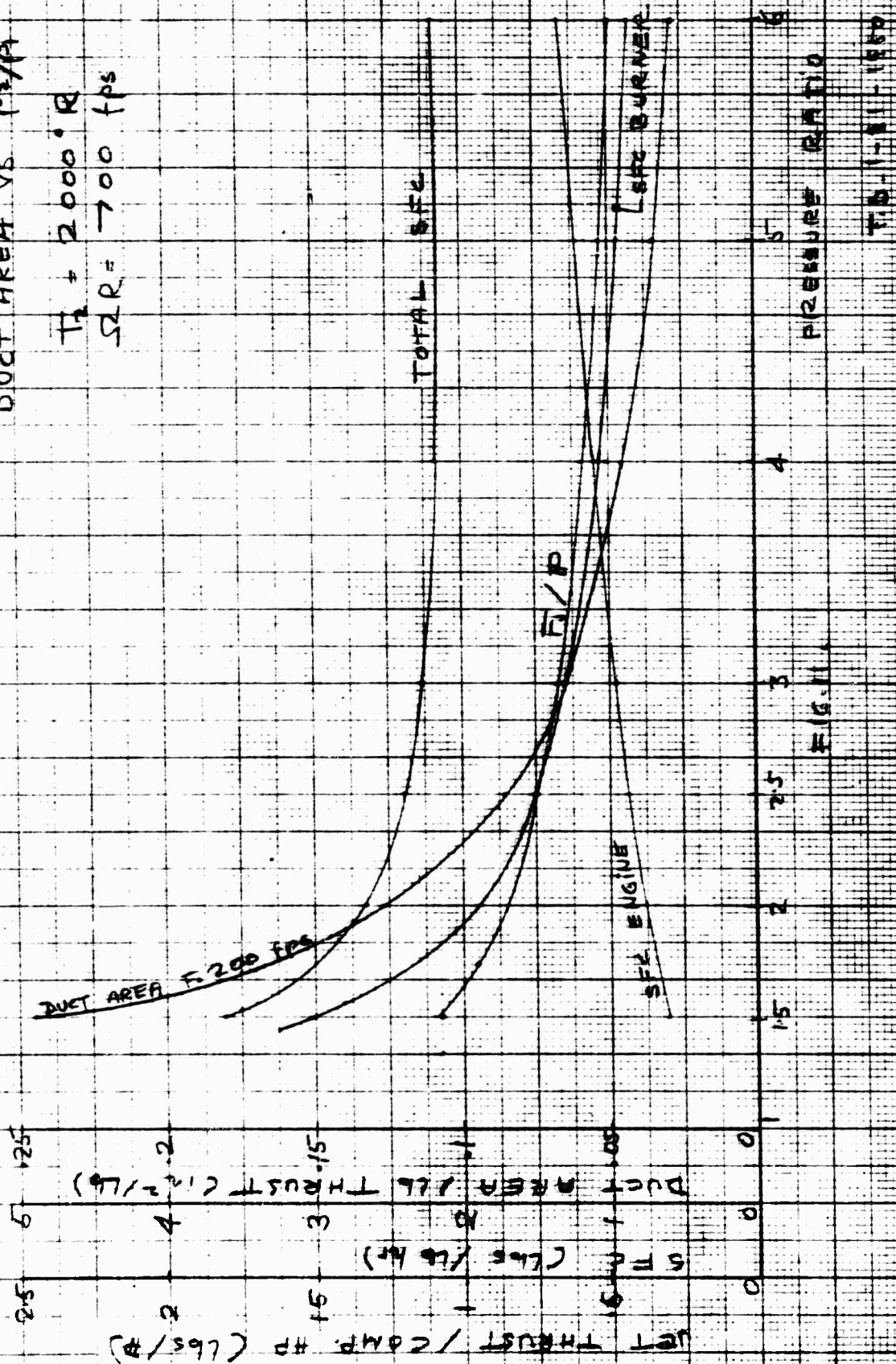


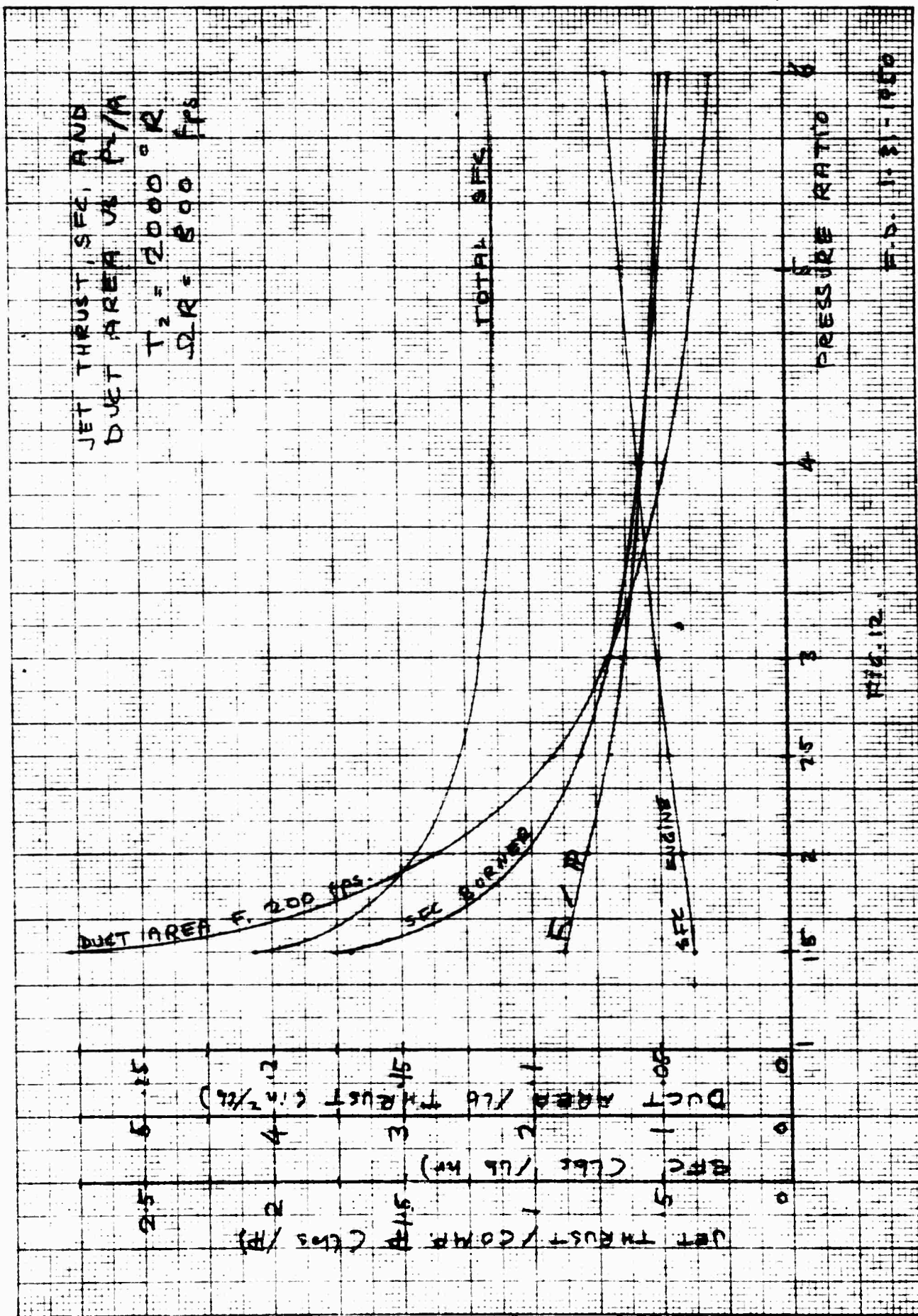
FIG. 11

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JET THRUST, SFC, AND
DUCT AREA VS P_2/P_1

$$\frac{T_2}{Q R} = \frac{30000}{500} R$$

2.5 5 7.5

JET THRUST / COMP. (lbs / lb)

DUCT AREA / LB THRUST (in² / lb)

SFC (lbs / lb hr)

DUCT AREA / LB THRUST (in² / lb)

DUCT AREA / LB THRUST (in² / lb)

DUCT AREA / LB THRUST (in² / lb)

DUCT AREA / LB THRUST (in² / lb)

DUCT AREA / LB THRUST (in² / lb)

DUCT AREA / LB THRUST (in² / lb)

TOTAL SFC

F_1/P

BURNER SFC

DUCT AREA FOR 200 HP

COMP. SFC

PRESSURE RATIO

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FIG. 13

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JET THRUST, SFC AND
DUCT AREA VS. P/P.

$$T_2 = 3000^\circ R$$

$$\Omega R = 600 \text{ fps}$$

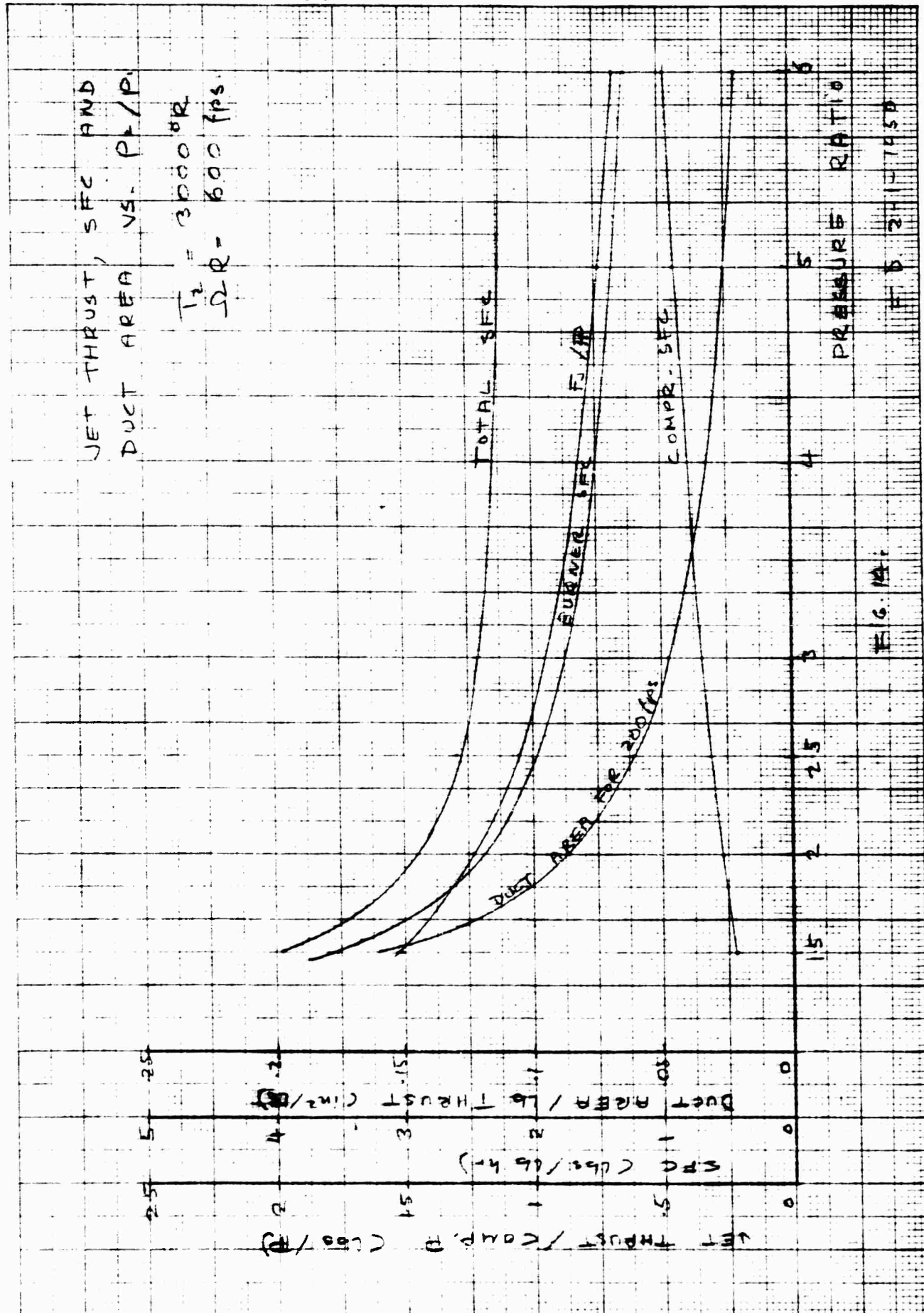
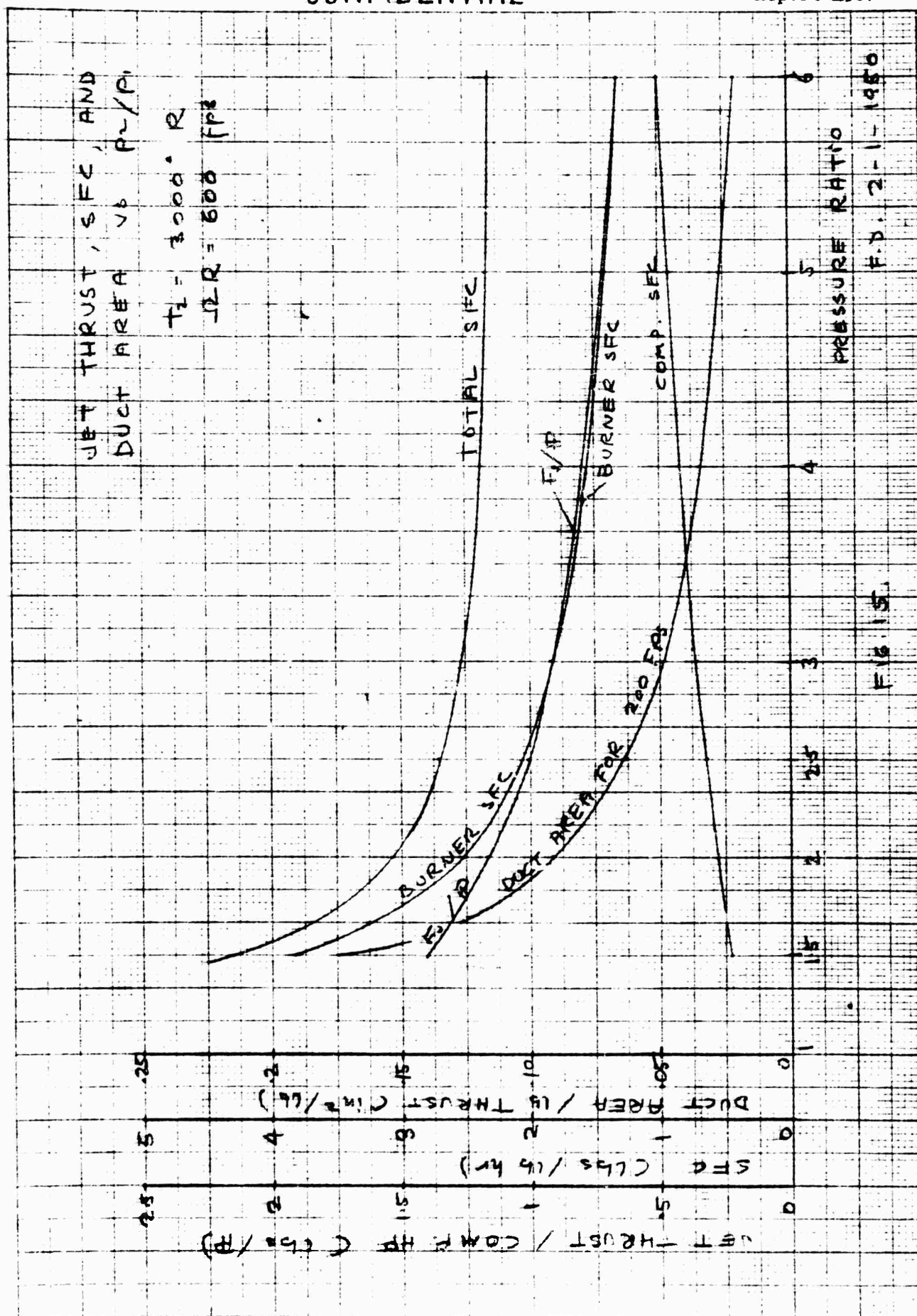


FIG. 14

Pressure Ratio

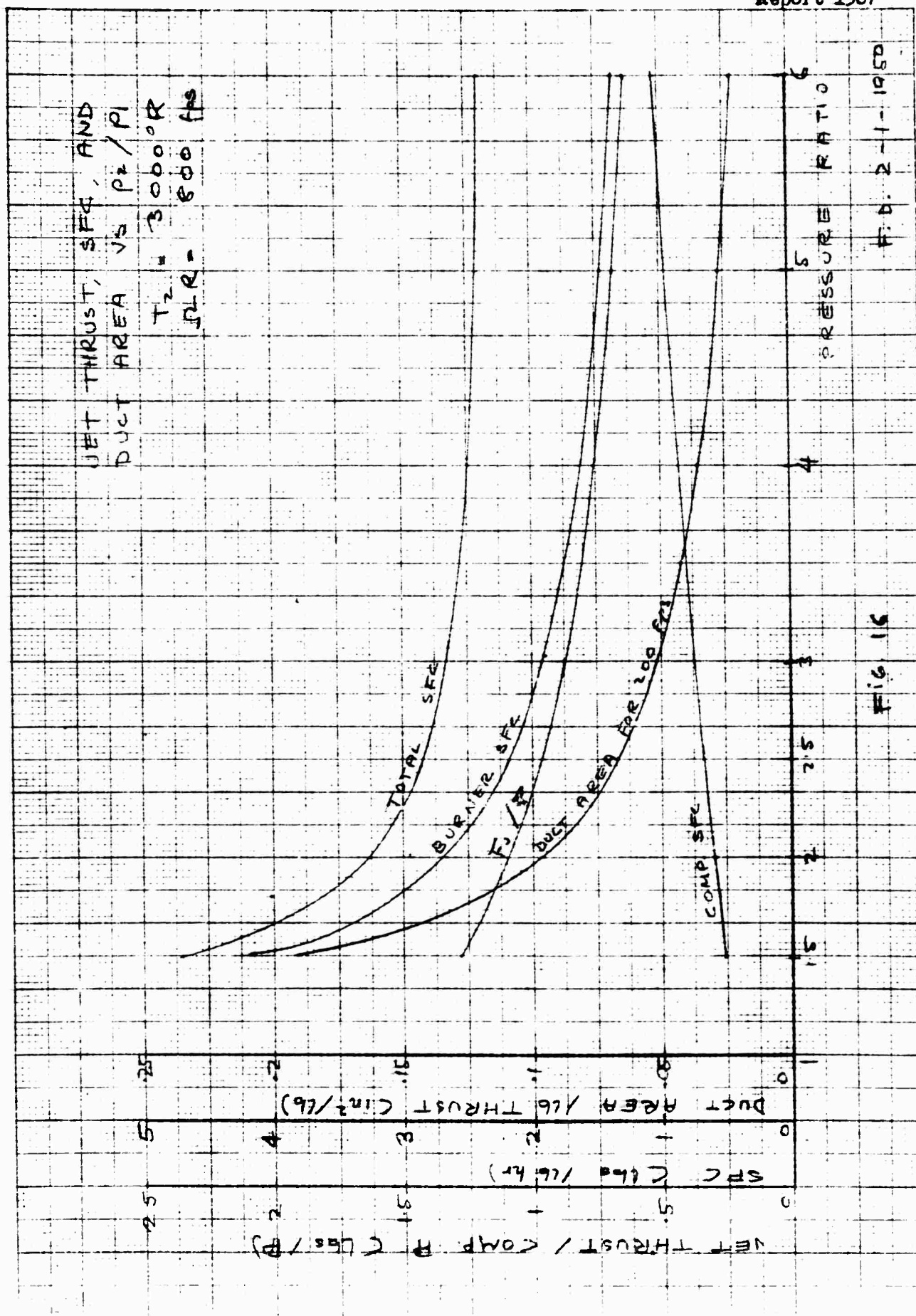
Pressure Ratio

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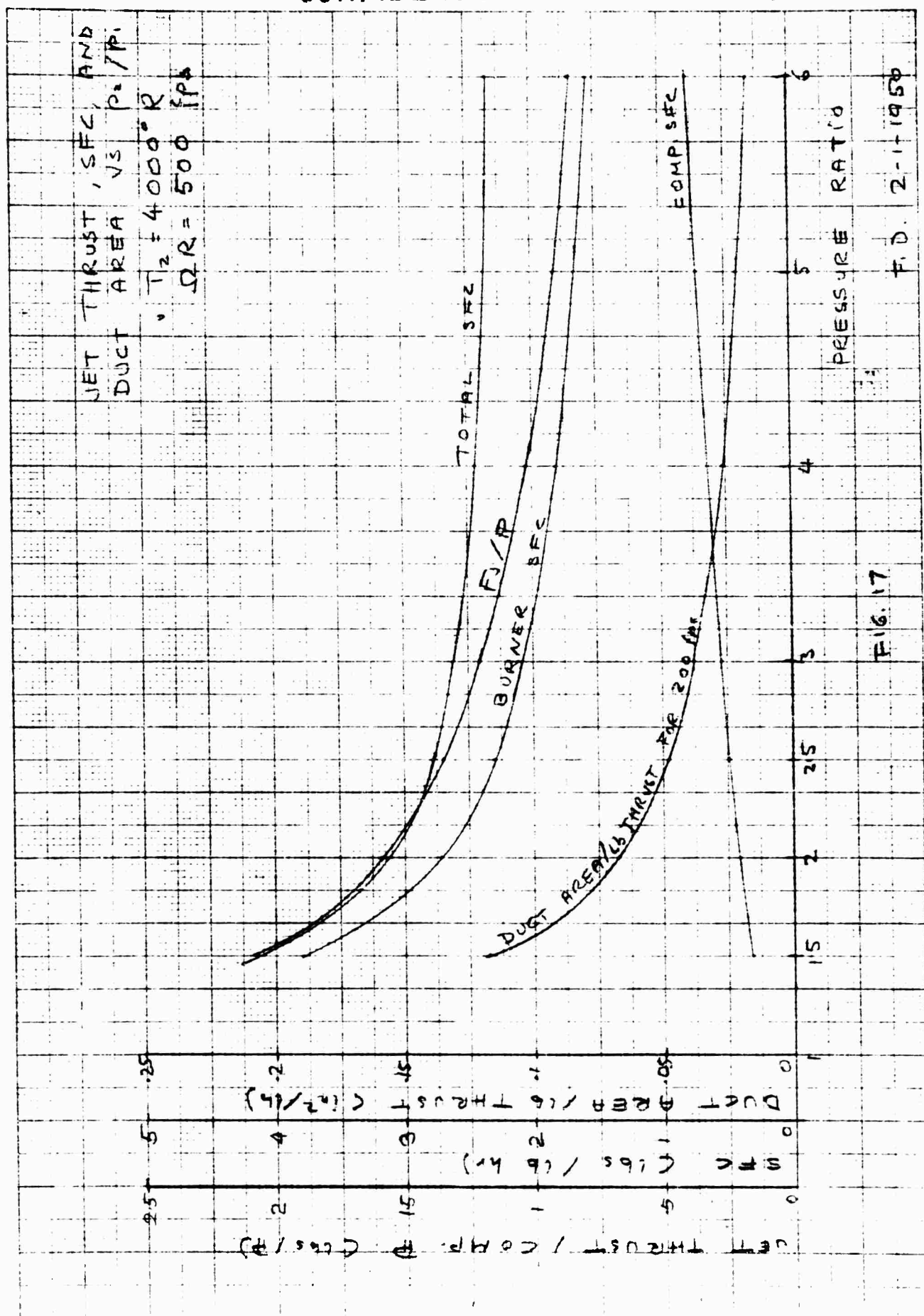


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JET THRUST, SFC, AND
DUCT AREA VS P_2/P_1
 $T_2 = 4000^\circ R$
 $\Omega R = 600 \text{ fps}$

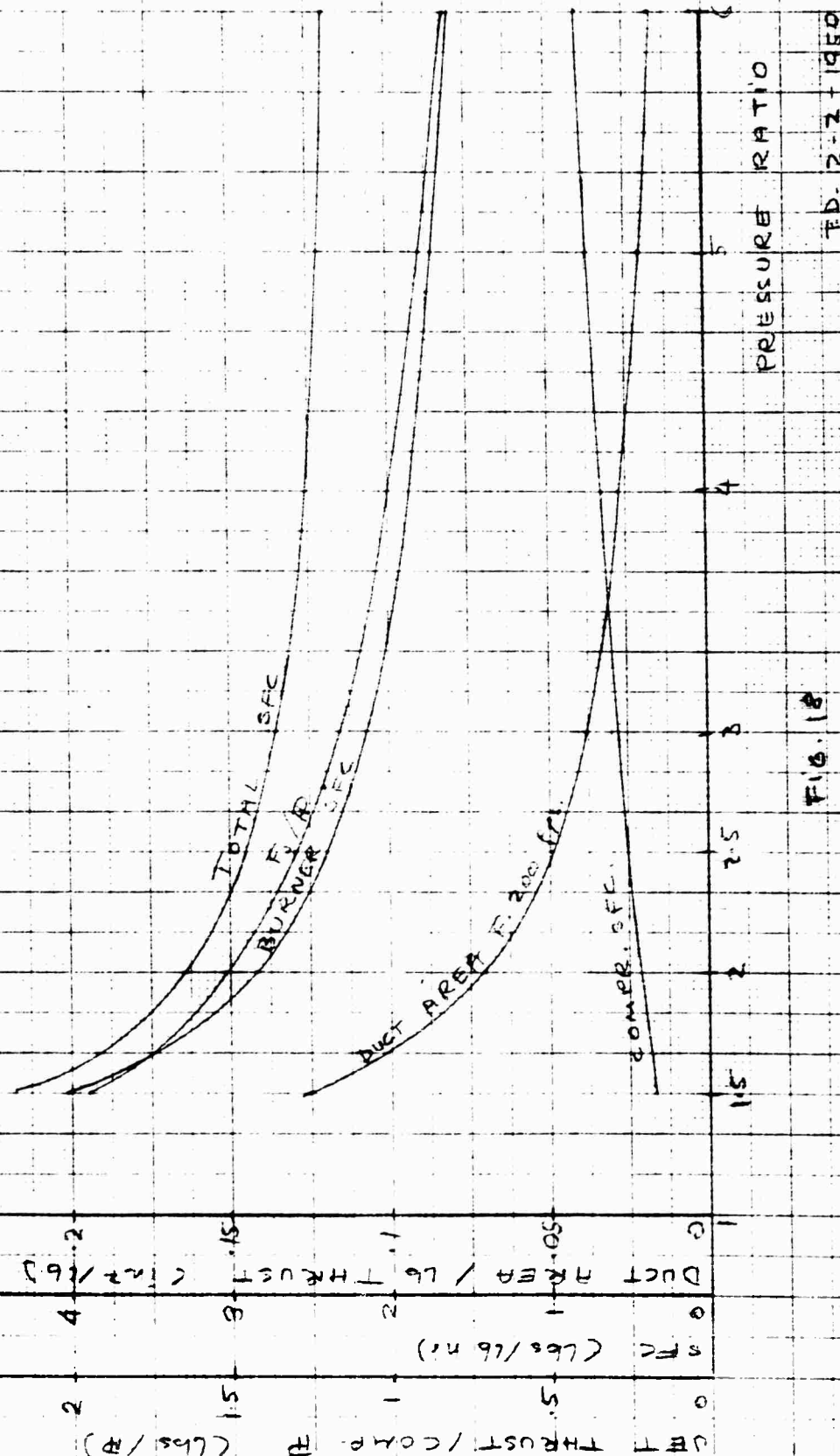


FIG. 18

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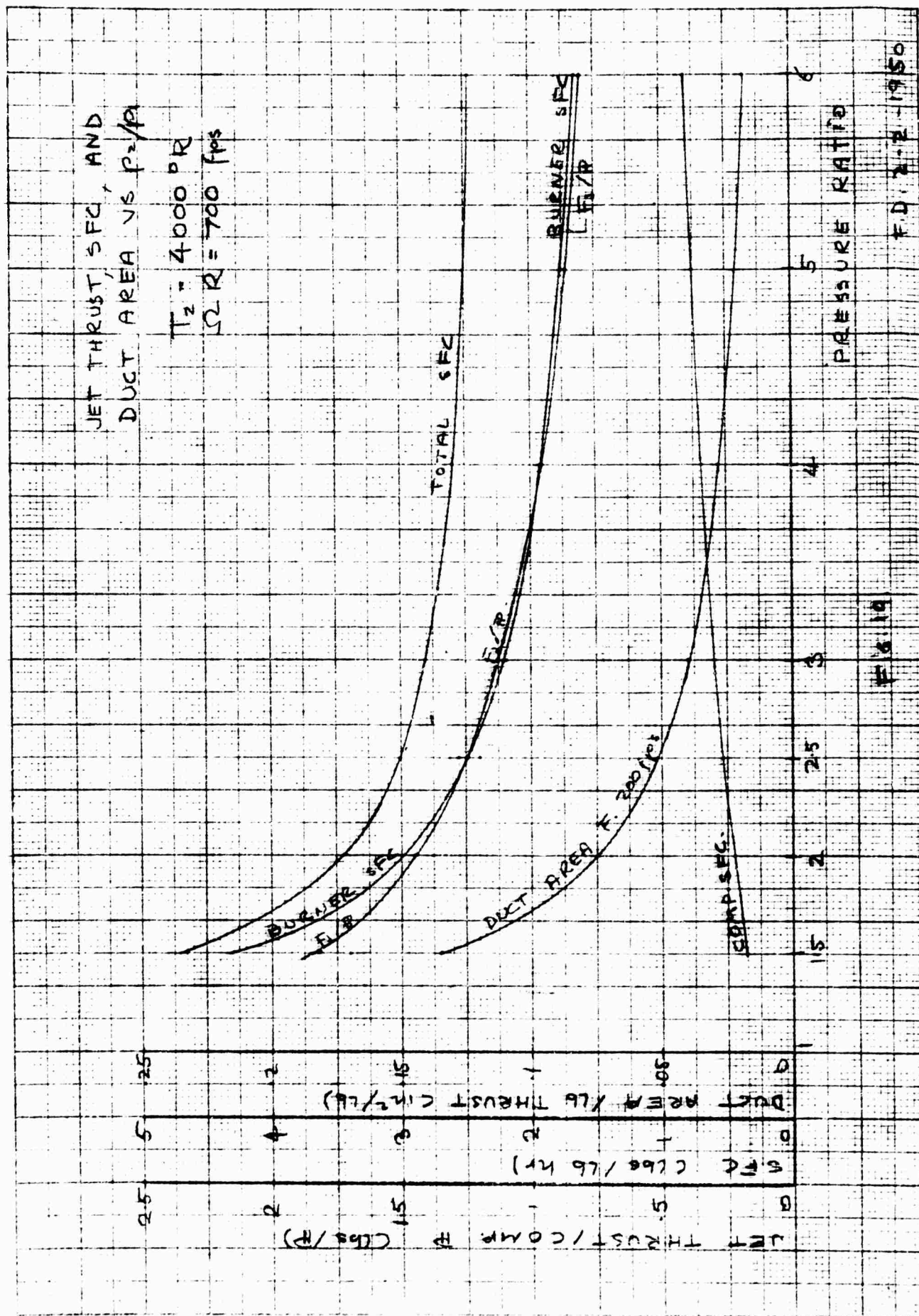
JET THRUST, SFC, AND
DUCT AREA VS P_2/P_1

4000 PR

$$\Sigma R = 700 \text{ lbs}$$

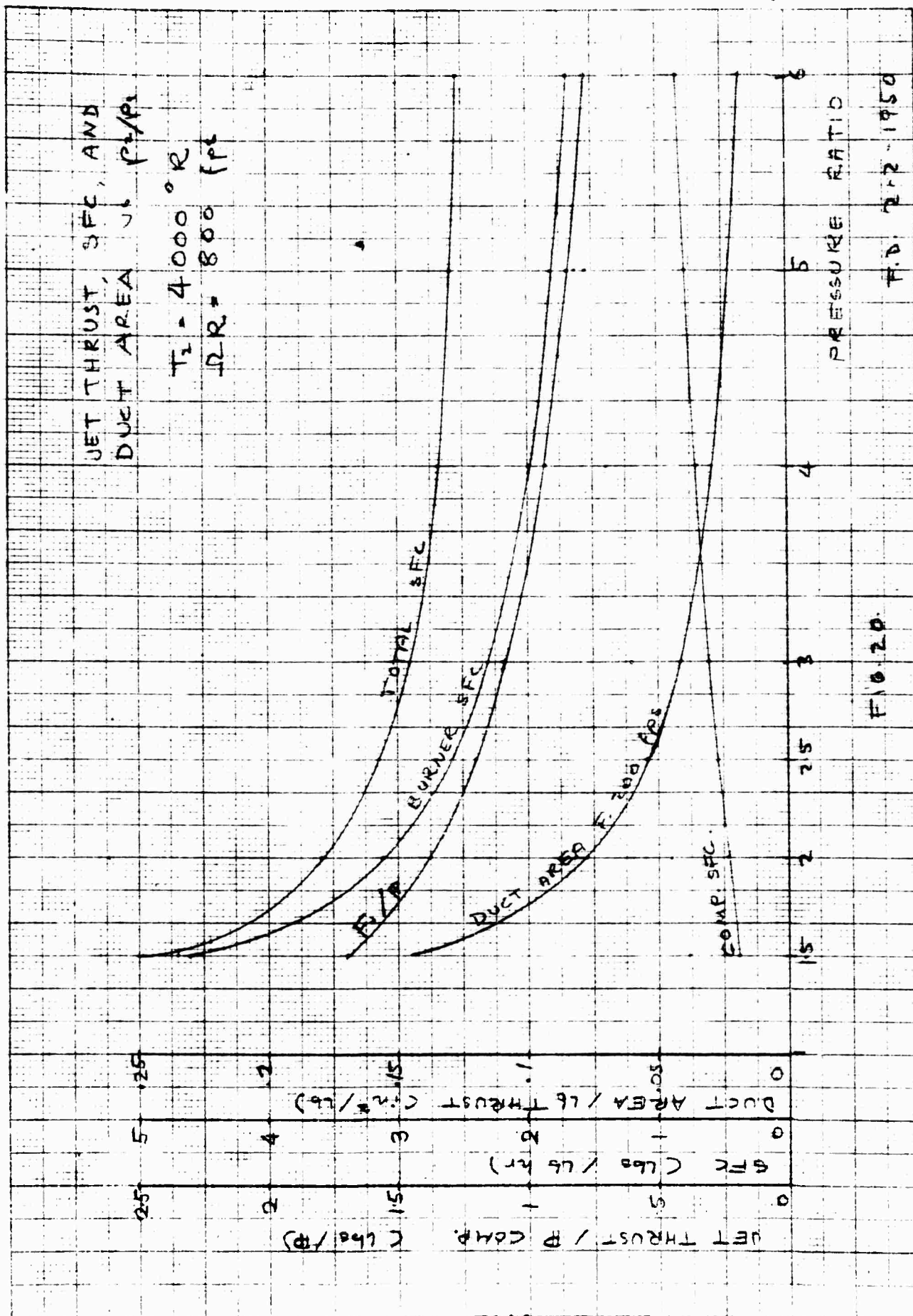
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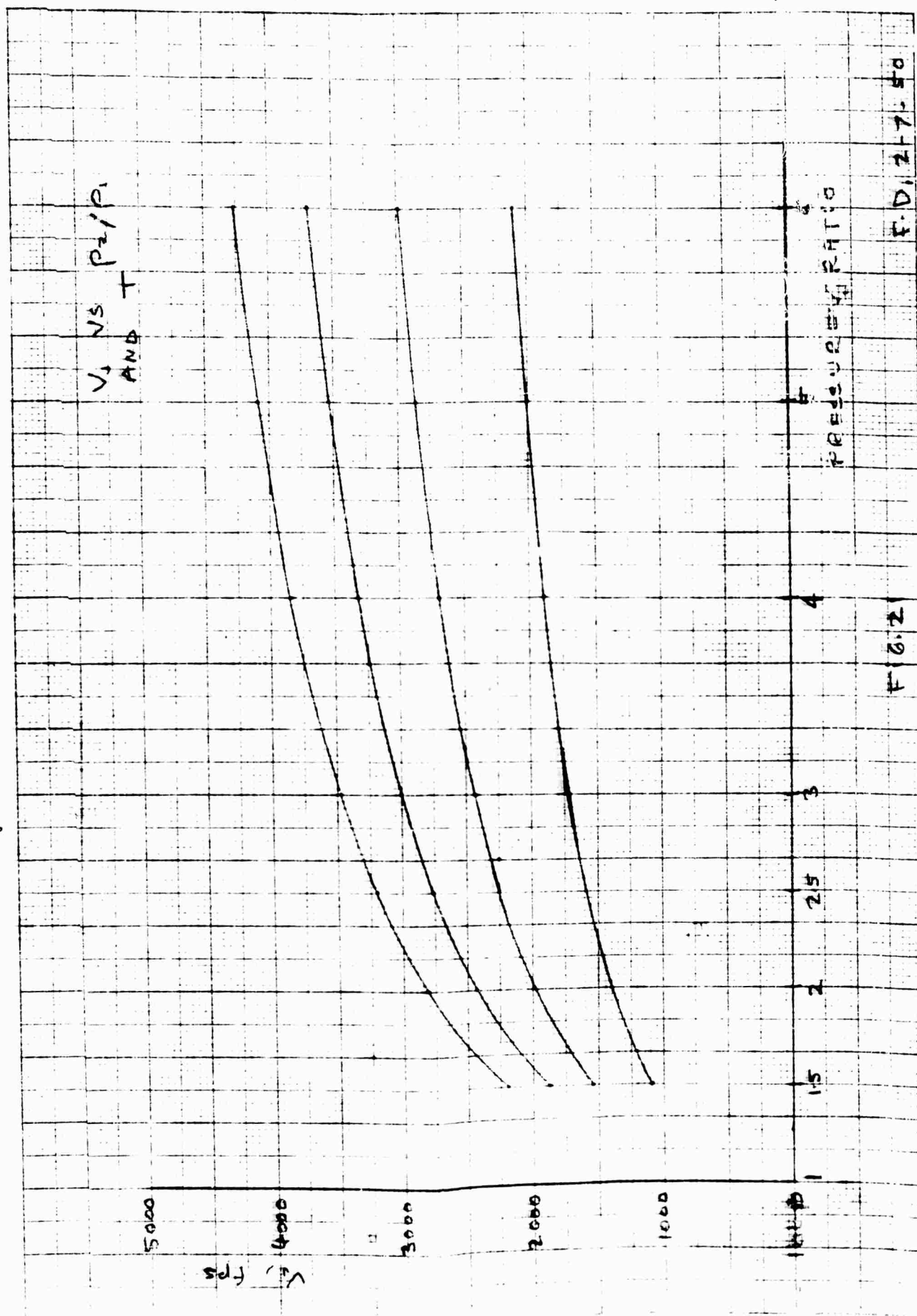
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